REDUCING SEVERE WEATHER DELAYS IN CONGESTED AIRSPACE WITH WEATHER DECISION SUPPORT FOR TACTICAL AIR TRAFFIC MANAGEMENT

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Abstract

Reducing congested airspace delays due to thunderstorms has become a major objective of the FAA due to the recent growth in convective delays. In 2000 and 2001 the key new initiative for reducing these convective weather delays was "strategic" traffic flow management (TFM) at time scales between 2 and 6 hours in advance using collaborative weather forecasts and routing strategy development. This "strategic" approach experienced difficulties in a large fraction of the weather events because it was not possible to forecast convective storm impacts on routes and capacities accurately enough to accomplish effective traffic flow management. Hence, we proposed in 2001 that there needed to be much greater emphasis on tactical air traffic management at time scales where it would be possible to generate much more accurate convective weather forecasts.

In this paper, we describe initial operational results in the very highly congested Great Lakes and Northeast Corridors using weather products from the ongoing Corridor Integrated Weather System (CIWS) concept exploration. Key new capabilities provided by this system include very high update rates (to support tactical air traffic control), much improved echo-tops information, and fully automatic 2-hour convective forecasts using the latest "scale separation" storm tracking technologies. Displays were provided at major terminal areas, en route centers in the corridors, and the FAA Command Center. Substantial reduction in delays has been achieved mostly through weather product usage at the shorter time scales. Quantifying the achieved benefits for this class of products have raised major questions about the conceptual framework for traffic flow management in these congested corridors that must be addressed in the development of air traffic management systems to utilize the weather products.

Introduction

In 2002 as well as the preceding six years, the delays during the summer months characterized by thunderstorms were significantly greater than the delays during the fall and winter months of the year that are characterized by low ceilings and visibility conditions. Analyses of delays at the Newark airport (see, e.g., Allen, et. al, 2001) have shown that convective weather is the largest single cause of delays with about two thirds of the convective weather delays arising from weather in and near the terminal area and other third of the convective delays due to weather in en route airspace.

In a substantial fraction of the US en route airspace, congestion from the user demand exceeding the fair weather capacity is a recurrent problem even in fair weather [OEP, 2002]. When convective weather causes the capacity in such regions to drop well below the fair weather capacity, delays go up dramatically and the overall system flows may exhibit instability phenomena in which apparently small changes in capacity result in very large delays and disruptions[1].

The FAA Operational Evolution Plan (OEP)[2] identifies improved severe convective weather decision support for en route and airport operations as key needs that must be addressed if the U.S. air transportation system is to alleviate the growing gap between the demand for air transportation and the effective capacity of the current National Air System (NAS).

Reducing en route convective delays is very challenging. It is difficult to balance flows when congestion occurs in en route airspace and convective weather impacts are very difficult to forecast accurately with lead times (> 2 hours) needed to accomplish effective air traffic management (ATM) using today's decision support tools. The problem is further compounded in congested major corridors by the interactions between flows to and from major terminals with en route traffic.

Hence, at the last Air Traffic Management (ATM) seminar, we proposed (Evans, 2001) that there needed to

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[1] For example, scenarios A and B at http://www.faa.gov/programs/oep/Archive/scenarios/scenarios.html show how small perturbations in traffic flows can cause large scale disruptions to the air system.
[2] See http://www.faa.gov/programs/oep/Archive/

be much greater emphasis on improving the tactical[3] ATM decision support capability by a combination of improved weather predictions together with automation and traffic flow management tools to generate and evaluate rerouting options on an ongoing basis.

In this paper, we describe initial operational results from a major new FAA initiative, the Corridor Integrated Weather System (CIWS), to improve tactical convective weather decision support for the highly congested en route airspace associated with the Great Lakes and Northeast corridors (Fig. 1) and the terminals within that airspace,

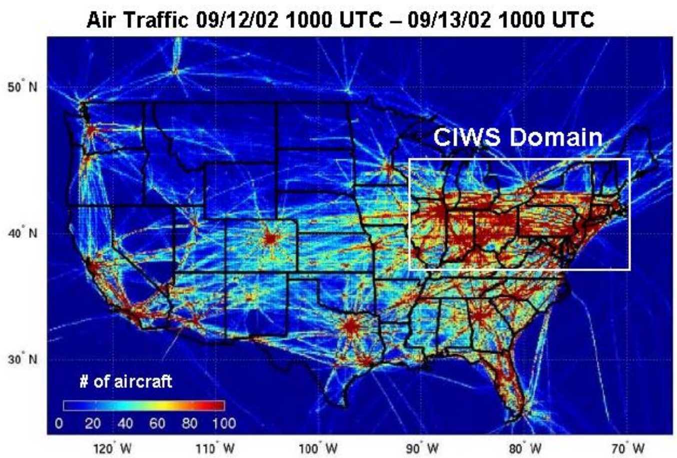

Figure 1. Coverage of CIWS in 2002.

The paper proceeds as follows. First, we describe the weather products provided in the 2002 demonstration. Then we summarize the operational feedback provided by the users. Two cases where significant benefits were achieved are presented. The issues that arise in quantitative delay reduction benefits assessments are discussed in some detail since they raise significant questions about the paradigm that should be used to characterize capacity constraints in congested airspace. The paper concludes with a discussion of key issues for weather and ATM integration to further improve the congested corridor severe weather delay reduction that can be achieved by a tactical approach.

CIWS Mission Needs/Operational Concept

The current en route convective weather decision support system is deficient on many time scales [Evans, 2001; Evans, et al., 2002]. Mosaics of NEXRAD products are the principal current source of information on storm locations and severity. NEXRAD product data anomalies (e.g., AP-induced ground clutter and system malfunctions) and the product timeliness have been a concern for tactical Air Traffic Control (ATC). Further, the current NEXRAD algorithm used to estimate storm echo tops generally underestimates the tops.

Existing operational convective forecast products within en route airspace are also limited. Most en route weather decision support systems such as the Weather and Radar Processor (WARP) show only current and past storm locations. The Aviation Weather Center provides two products: 1) the National Convective Weather Forecast (NCWF) with one-hour forecast contours, and 2) the Collaborative Convective Weather Forecast Product (CCFP) 2, 4, and 6-hour predictions that are updated every four hours. The spatial and time resolution of these forecast products is not adequate for congested airspace operations and there is an urgent need to improve the product accuracy.

The Integrated Terminal Weather System (ITWS) [Evans and Ducot, 1994] provides high space/time resolution products with a data quality commensurate with direct use by ATC. However, the current operational ITWS system provides only 20-minute forecasts and has limited potential to dramatically extend its forecast period due to the sensor coverage limitations. Additionally, it has become clear that addressing critical needs such as higher departure rates from airports in congested airspace during convective weather requires much greater coverage for forecasts than can be provided by the current ITWS.

To address this need for improvements in forecast capability and timeliness of all weather products, the operational concept for the CIWS is full automation in the generation of all weather products with the products being provided directly to non-meteorologist FAA and airline users. Since these operational users must rapidly make ATM decisions, it is very important that there be a high integrity in all of the CIWS products to minimize the need for meteorological interpretation. Since the driving application for CIWS is improved operations in congested corridors, the space/time resolution of the products must be comparable to those of ITWS.

CIWS Implementation for 2002

The focus of testing in 2002 has been on the highly congested Great Lakes and Northeast Corridors shown in Fig. 1. This region was chosen so that the problems associated with the most demanding user needs would be addressed at the outset of the program.

[3] By tactical ATM, we use the ICAO terminology to consist of "tactical ATC" which operates in the 0-30 minute time scale as well as "tactical" traffic flow management (TFM) in the 30 min-120 minute time scale.

Sensors Used

Both terminal and en route weather sensors were used to create the improved convective weather products. The NEXRAD volume scanning Doppler weather radars are used to determine the three dimensional structure of storms. To significantly improve the effective rate at which the full surveillance volume is scanned, the terminal ASR-9 fan beam radar is used to provide a weather product with a volume update of at least once per minute. The ASR-9s cover over 60% of the area shown in Fig. 1 (see Evans et. al, 2003 for the ASR-9 coverage).

Product Generation Algorithms

The concept exploration phase uses vertically integrated liquid water (VIL) as the precipitation product because VIL is a better indicator of storm severity and new growth and is less susceptible to AP and other data anomalies than other precipitation representations, such as composite reflectivity.

One of the significant issues to resolve in the CIWS testing was the mitigation of the underestimated storm echo tops from the current NEXRAD echo tops algorithm. The radar echo tops are particularly important in the en route domain with the rapid transition to regional jets for commuter operations. Studies of air carrier pilot preferences in en route airspace near Memphis TN. [Rhoda, et. al, 2002] have shown that pilots will typically fly over storms when the aircraft altitude is at least 5 kft above the storm radar echo tops. However, the current operational NEXRAD products underestimate tops by as much as 12 kft. An improved echo tops algorithm has been developed for CIWS that more accurately estimates the true storm echo tops (see [Evans, et. al, 2003] for examples of the differences in echo tops).

Since the CIWS coverage region in Fig. 1 is a very large expanse, it is clear that radar mosaics are necessary. The mosaic algorithm used for CIWS advects the data from the various radars before combining so that errors in weather location arising from the asynchronous nature of the radar measurements can be significantly reduced.

Two separate storm tracking and forecast algorithms are used. The ITWS storm tracking algorithm is used to generate the cell motion vectors and 10- and 20-minute storm extrapolated positions (SEPs).

The Regional Convective Weather Forecast (RCWF) is used to generate all of the longer lead-time forecast products. The technology used to generate the RCWF is described in Boldi, et al. 2002. Key features in the algorithms used for the CIWS 2002 demonstration are:

- Explicit estimation of storm growth and decay to allow growth and decay trends to be incorporated into forecasts,
- Scale separation technology to regionally classify convective precipitation by type (see fig. 3) so as to optimize tracker performance on a regional basis,
- The use of satellite data in conjunction with radar data, and
- Real time metrics for the current forecast accuracy that assist the user in estimating the forecast utility as a function of forecast time and location within the CIWS domain.

The forecast results are portrayed via time lapse animation of 60 minutes of past weather and 120 minutes of forecast weather in 15-minute increments. The probabilistic forecast is depicted in three levels (low, moderate, and high probability) and represents a deterministic (but fuzzy) representation of the likely areas of level 3+ precipitation areas at each 15-minute time in the future. The forecast is created at 1-km resolution across the corridor, but displayed at 2-km resolution owing to bandwidth limitations to the user displays.

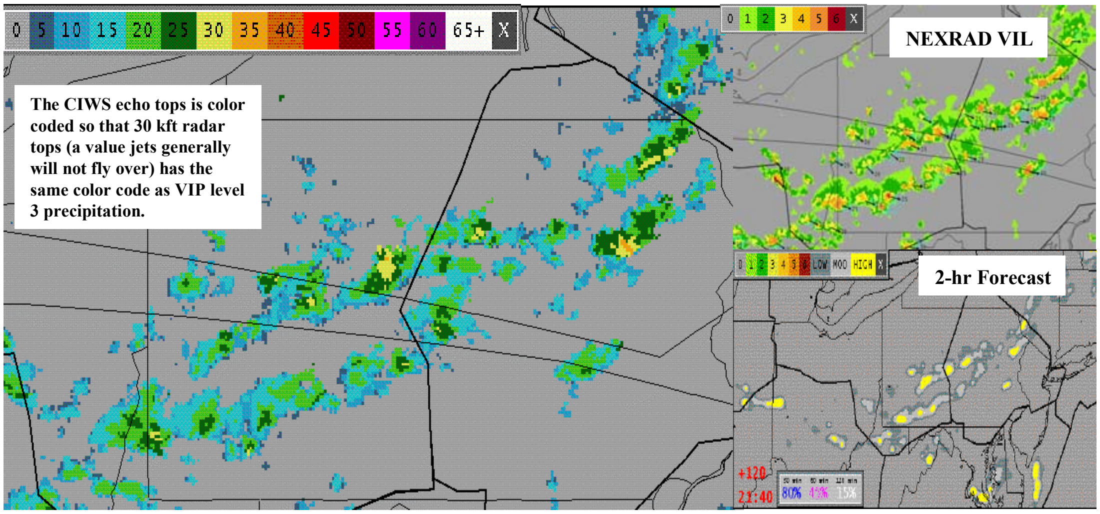

Figure 2. CIWS display during the severe weather event of 24 August 2002. The RCWF provides CIWS 15 to 120 minute animated forecasts (left hand window). A key feature is the real time indication of forecast accuracy (not shown). The two windows on the right show the NEXRAD VIL mosaic and echo tops map products. The echo tops product shows that high level VIL returns are associated with relatively low echo tops.

User Display

Figure 2 shows the multi-window user display. The upper right hand window shows the NEXRAD VIL precipitation with cell motion arrows and SEPs. The lower right hand window shows the RCWF time lapse animation described above. The left hand window shows the storm echo tops product.[4]

Since radar echo tops are a particularly important factor for flight routing in the en route environment, the echo tops are portrayed with a 2-km spatial resolution that matches the precipitation spatial resolution and has the colors assigned in such a way as to facilitate air traffic management decision making. Since echo tops of 30 kft are a key "threshold" for storm avoidance by jets- analogous to VIL level 3 precipitation- the echo tops color code for this flight level has been chosen to match the VIL level 3 color code. This facilitates rapid traffic flow decision making by non-meteorologist users (e.g., if either the precipitation or echo tops colors in a given region are all blues or greens, pilots are likely to accept routing through that region).

Color situation displays are in operation at 6 key en route centers[5], the FAA's Command Center, and 6 TRACONs[6]. By August of 2002, there were 30 dedicated CIWS displays at FAA facilities. Airline systems operations centers were provided access to the CIWS products via servers on the Internet and CDM-Net as well as having dedicated situation displays identical to the FAA user displays.

At en route facilities, CIWS displays typically are in close proximity to the existing Weather and Radar Processor (WARP) displays with NEXRAD mosaic composites at the same facilities. Additionally, the Enhanced Traffic Management System (ETMS) displays in the same vicinity have vendor-provided NEXRAD mosaics (different from the WARP mosaic). Hence, the operational users had multiple sources of information on severe convective weather that could and would differ as to weather location and severity.

Operational Usage of CIWS Products

Operational Period

Operational usage of the CIWS products commenced in early July 2001. In April of 2002, the system started near-full-time operations (seven days per week, 24-hours per day with occasional downtimes for upgrades and maintenance). This schedule continued through the 2002 convective storm season with several one-day shutdowns for software and hardware upgrades.

[4] Not shown is an optional window with an ASR-9/NEXRAD mosaic. The users can also have satellite data as a background to the radar mosaic data.

[5] Chicago, Cleveland, Boston, New York, Washington and Indianapolis

[6] New York, Chicago, Detroit, Pittsburgh, Cincinnati, and Cleveland

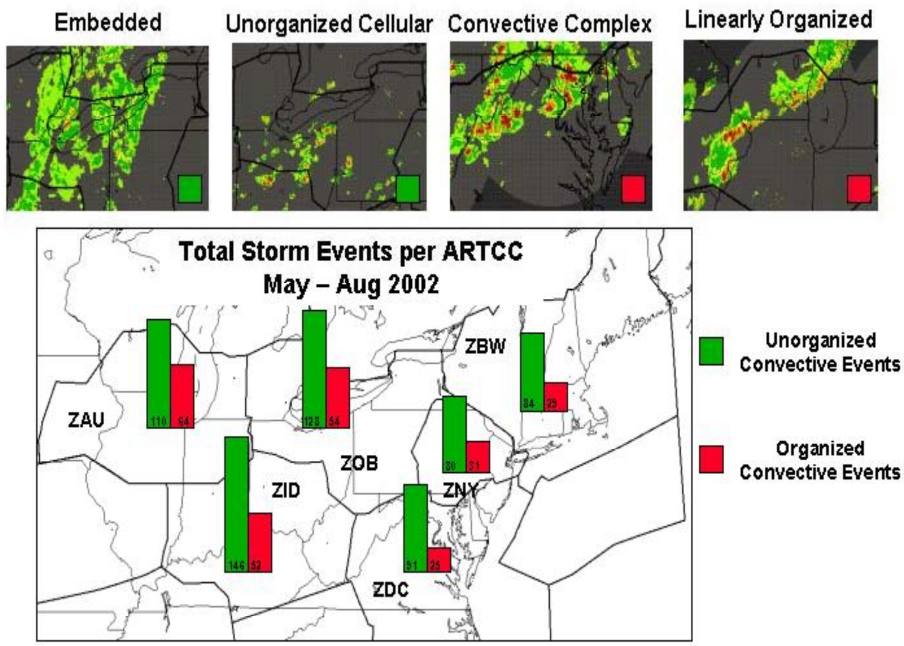

Figure 3. Types of convective weather encountered in 2002 within CIWS domain.

Convective Weather Impacts During Demonstration

Figure 3 shows the frequency of weather impacts on selected en route centers during the summer of 2002. The very high frequency of days with storms (e.g., 128 "unorganized" events and 54 "organized" events in the Cleveland en route center) reflects the tendency of storms to move from west to east over a period of days as well as days with multiple events. Terminal impacts are shown in Table 1 below.

 # Days with ATC Impact from Storms

Airport	D< 1 hr	D>1 hr	GS	GDP
BOS	12	7	7	5
CVG	23	4	27	1
DTW	22	9	19	9
EWR	50	32	31	10
IAD	29	17	22	1
PIT	10	1	19	0
ORD	50	26	29	23

Table 1. Days in summer of 2002 with thunderstorm impacts on various airports. D= delays in hours, GS = ground stop and GDP = ground delay program.

The weather impacts shown in Figure 3 are much higher than would be expected from standard thunderstorm day statistics for the various locations.[7] This reflects the difference between statistics for areas versus point climatology as well as the occurrence of multiple convective weather events on single days. Table 1 indicates that the use of ground stops is much more common than the use of ground delay programs.

Operational User Feedback

Feedback was solicited both during and immediately following the weather events as well as in end of summer interviews. During events, the CIWS operations center personnel had access to real time flight track information as well as information on the use of displays at various facilities. Hence, the questions asked on the day of an event could be tailored to address particular issues. Unfortunately, the ability to obtain feedback on a given day varied greatly depending on both the workload of the CIWS operations center personnel and the ATC personnel at various facilities. Hence, the feedback on the day of events should be regarded as a "random sample" which was biased toward

[7] Chicago and Pittsburgh normally have 40 days with thunderstorm activity; New York has about 30 days per year.

facilities that had substantial weather impacts when feedback was solicited.

Figure 4 summarizes the results of the post-event interviews during the summer. Since this is a “random” sample of usage, the relative numbers of beneficial ATM decisions are the most meaningful aspect in Figure 4.

One of the important differences in benefits between the terminals in the CIWS domain and the earlier Integrated Terminal Weather System (ITWS) terminals at Memphis, Orlando, and Dallas is the much greater delay reduction benefits associated with departure operations as opposed to arrival operations. When the en route airspace is relatively un congested, we had found that the highest ITWS delay reductions arise from en route ATC proactively moving aircraft from one arrival transition area (ATA) (e.g., “corner post”) to another to minimize convective weather disruptions on flows into a terminal area.

In congested airspace such as the summer 2002 CIWS domain, it is much more difficult to move arrivals between ATAs in en route airspace, so ATC tended to halt departures and use departure airspace to handle arrivals. This causes a large queue of departures at the airport. As a result, there is a very high benefit associated with tactically determining opportunities to get more departures out when there is severe convective weather in and near the terminal area.

Post convective season interviews with users in October and November were conducted in two phases. Initially, we asked questions that would help quantify the benefits associated with key ATC decisions shown in Figure 4, similar to the approach taken for the NY ITWS benefits study (Allen, et. al, 2001). This approach was successful at the terminal areas, but not at the en route centers. In en route airspace, there is a wide variety in traffic demands during convective weather due to strategic rerouting. Also, en route traffic flow managers seem much less aware of rates for operations than are terminal managers. Finally, it is harder in en route airspace to assess delay impacts of decisions such as keeping a route open longer and/or earlier. These factors made it difficult for en route users to provide quantitative estimates for the “average” benefit associated with various decisions that were improved by the use of the CIWS products. Rather, it was found that the better approach was to discuss how the CIWS tactical products were used on specific events and then generalize based on analysis of many events.

Route Impacts / Traffic Flow Management

CIWS Benefit	Documented Occurrences
• Jet Routes Reopened Earlier	9
• Proactive, Efficient Reroutes	7
• Efficient Planning of Ground Stop, Ground Delay Programs *	6
• Reduced MIT Restrictions	5
• Routes Kept Open w/o Deviations	5
• Traffic Directed Through Gaps	5
• Reroute Advisories Cancelled Early	2
• CIWS Used to Direct Pathfinders	1

* Considered Terminal Impact Benefit as well

Terminal Impacts

CIWS Benefit	Documented Occurrences
• Extra Departures from Terminal	9
• Arrival Approaches Kept Open	3
• Avoided Reroutes on Approach	2
• Increased Airport Arrival Acceptance Rate (AAR)	2
• Avoided Airport Ground Stop	2

Users Providing Benefits:

- ARTCC: ZOB, ZAU, ZID, ZNY, ZDC
- TRACONS: NY, CVG, PIT, DET, CHI
- Airlines: Northwest, Continental, United
- Command Center

Figure 4. Post event feedback on operational utility of CIWS products.

The end of season interviews identified several key factors that were not apparent in the post event feedback summarized in fig. 4:

a. The utility of the echo tops product for identifying opportunities to keep routes open longer and reopen earlier increased dramatically at certain facilities (especially ZOB and ZNY) after the new product was introduced in mid August.
b. The operational impact of the 2-hour convective weather forecast (also introduced in mid-August) was reduced by the type (mostly “unorganized” storm systems) and decreased frequency of convective weather at the end of the summer.
c. The ability to tactically move en route traffic between routes when there are convective weather impacts depends critically on the locations of the flight origin (O) and destination (D) with respect to the en route facility. When the O or D lie within an en route facility (or are close to the facility boundary) there is a high degree of tactical flexibility. By contrast, when both the O and D lie outside an en route facility, rerouting an aircraft typically requires coordination between several en route facilities and the Command Center. The high workload associated with this coordination results in many missed opportunities to tactically move flights between routes.
d. The conceptual model that en route traffic flow constraints are captured by sector capacities (e.g., as used in the ETMS “sector alerts” and captured in the FACET planning tool [Billimoria, 2001]) was often not useful for understanding operational TFM between major terminal complexes such as NY and Chicago during convective weather. Rather, the operational users were much more likely to exercise traffic flow constraints using route-based metrics such as miles-in-trail (MIT).

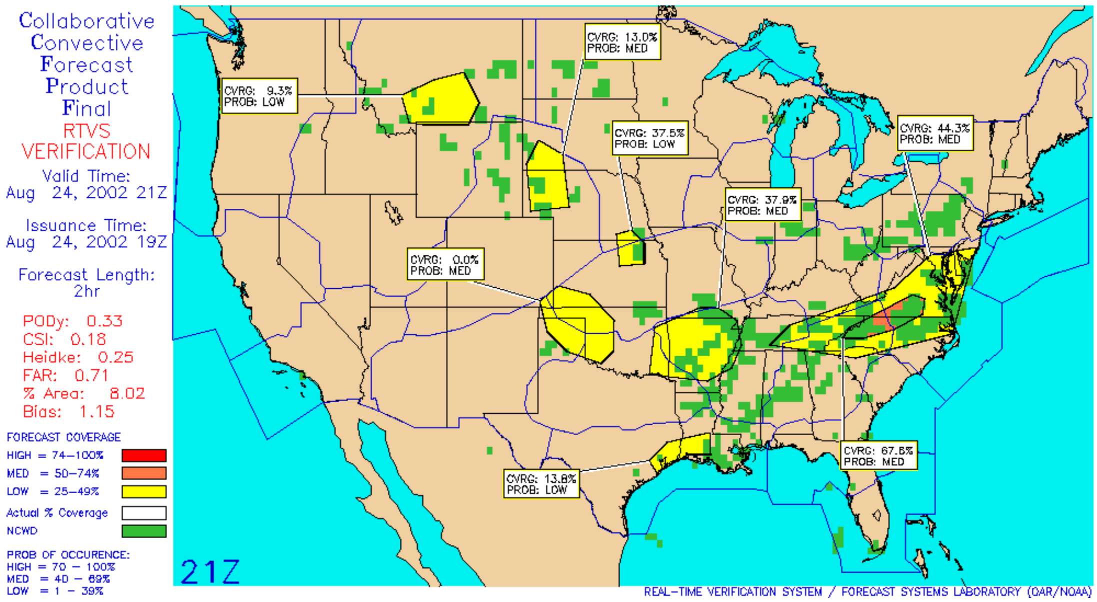

Figure 5. CCFP forecasts (yellow and red) and actual convective weather (green regions) on 24 August 2002 at 21Z.

An important factor in this route-based approach assigned to specific airports at distances as great as 1000 km from an airport (e.g., the allocation of specific routes to EWR, JFK and LGA at the Indiana/Cleveland border). Also, the users indicated that it was difficult to determine which aircraft should be delayed and/or rerouted when a significant demand/capacity imbalance developed suddenly in some sectors due to convective weather.

As a consequence of the tendency to rely on route volume based approaches to managing traffic flows plus the tendency to allocate major jet routes to specific destinations, it was much more difficult to solve convective weather induced problems by a series of "local" tactical solutions. Rather, there was a tendency to look for large scale rerouting opportunities that would involve rerouting many aircraft at a time to alternative routes that were quite a distance from the "nominal" route for an O-D pair. Such major opportunities were difficult to forecast in advance (especially given the "unorganized" nature of the convective weather encountered much of the summer).

e. Routes were rarely if ever closed in advance of a weather impact using the CIWS forecast products. Rather, there was a tendency to keep the routes open as long as possible until pilots refused to use the route. Making tactical ATC adjustments (e.g., using the CIWS very short term storm forecasts and/or echo tops) information to minimize pilot route refusals were cited a number of times as operationally useful.

f. Conversely, reopening full volume usage of routes after the weather impact ended was often slow to occur. An important factor was the tendency to rely on reports from a "path finder" before releasing significant numbers of planes along a route as opposed to using the storm forecasts. Since it might take 20 to 30 minutes for a "path finder" to probe a route, it could take up to an hour to achieve full volume usage of route after the weather impact had ended. We anticipate significant improvements in the ability to resume full volume usage of routes as the users gain more confidence in the CIWS echo tops and forecast products that were introduced in the late summer of 2002.

Analysis of Specific Events

In this section, we consider specific terminal and en route events that are typical of the operational uses observed in 2002, and which highlight some of the issues that one must address in reducing the delays. The first of these is a ground stop event that is of significance because ground stops appear to be much more commonly used in the CIWS domain to address terminal convective weather impacts than are ground delay programs.

Terminal/Transitional En Route Operations Event

On July 18, there was scattered convective weather in an around the Pittsburgh terminal area (PIT) with scattered precipitation through Ohio and Pennsylvania. Using the CIWS storm motion and echo tops products, the PIT TRACON and the Cleveland en route center determined that the storms would move very close to the airport as well as block at least one of four ATAs, but that:

a) there would be gaps between cells in the terminal area, and
b) two or three of the ATAs would remain open at various times in the future

They concluded that tactical adjustments could probably handle the 24 aircraft expected between 2015 and 2115 and imposed no traffic flow constraints. They were successful in achieving continued operations throughout the period.

It was the opinion of the operational users that had they not had the high space/time resolution and quality of the CIWS products (e.g., had they relied on their previous weather information), they would have imposed a "second-tier" ground stop (GS) between 2015 and 2115 for flights to PIT that would have entailed holding planes as far away as Denver, Orlando and Salt Lake City. The issue that then arises is how to compute the delays that would have occurred if the "second-tier" GS were invoked.

One important issue is how long it takes after a GS ends before a flight can take off. Discussions were held with the major airline that hubs at PIT to determine what would be done with the planes and passengers during a prolonged GS if a flight were loaded versus not yet loaded. Based on the guidance furnished by the airline, it was concluded that approximately 20 hours of direct delay and 16 hours of downstream delay were averted assuming that:

a. there were no overloads of en route facilities when ground stopped aircraft would have been released, and
b. PIT would not have experienced queue delays due to excessive demand when the ground stopped aircraft arrived along with planes that would normally arrive at PIT after 2115.

Studies are underway to determine if there would have been landing queues if a ground stop had been used and to determine the delay reduction associated with other adverted ground stops.

En Route Operations Event

On 24 August 2002, there was convective weather along a SW to NE axis that moved through Ohio and Pennsylvania. Fig. 5 shows the CCFP forecasts issued at a representative time in the 12-hour period for which the weather system persisted. Both the ETMS weather depiction, the CIWS precipitation product, and the actual weather precipitation product used for CCFP validation suggested that the east-west routes through Pennsylvania that service the New York airports and Philadelphia would be blocked for about 10 hours of the 12hour period.

However, as can be seen from Figure 2, the storm echo tops were typically less than 30 kft. By using the CIWS echo tops product to identify appropriate tactical routing around the few high-topped cells, ATC was able to keep the routes through Pennsylvania open for the entire 12-hour period.

Analysis of the flight track data showed that 734 aircraft to or from JFK, LGA, EWR, and PHL flew over the low-topped storms for the 10 hours during which it appeared, on the basis of storm reflectivity alone, that the routes would have been blocked.

Estimating the delays that these aircraft (and others) would have encountered had they not flown over the storms has proved to be a very challenging exercise that highlights many of the ATM challenges in addressing this type of major convective weather event.

A crude estimate of the delay reduction is obtained by assuming that the planes would have been delayed at least for the period during which the storm reflectivity suggested that the routes were blocked. This yields a delay savings of about 3,300 hours with a monetary value of over $ 10.5 M[8].

There are two additional factors that need to be considered:

1. Airport queues and
2. En route congestion

Given the very large number of flights that flew over the storms, there surely would have been queues at the airports when the weather impacts ended that would have further increased the delays. On the other hand, some fraction of the planes could have been rerouted to the north or south of the weather-impacted area in Ohio and Pennsylvania. The difficulty in assessing the possibility for rerouting the aircraft is that there also was a

[8] The delay savings include down stream delays and the delay time to monetary conversions discussed in Allan, et. al., 2001.

significant convective weather system stretching from Arkansas through North Carolina that resulted in a high volume of traffic through the convective weather free region in Kentucky and Virginia (Fig. 5).

Hence, for this case one needs to have a model that could determine a feasible allocation of flight route allocations and ground/airborne delays for a large fraction of the NAS air carrier flights over a 12-hour period to bound the disruption that would have occurred had not the over flights been possible.

To the best of our knowledge, the only model that has the potential for "optimally" making such an allocation is the model of Bertsimas and Patterson (1998). Work is underway to apply that model to cases such as 24 August. However, there are some issues that need to be resolved before the Bertsimas model can be applied to cases such as 24 August:

1. The model characterizes en route capacity constraints by sector capacities as opposed to the route capacities that appear to be typical of operational TFM in congested corridors,
2. Validated algorithms are needed to relate the coverage of operationally significant weather in a sector (or near a route) to the effective capacity of the sector or route, and
3. The computational algorithms need to be improved so that cases of multi-hour ground delays for a large number of flights and many O-D pairs have feasible computation times.

Integration of ATC/TFM Decision Support Systems with the CIWS Weather Products

The CIWS weather products can only be successful in reducing the delays due to convective weather if the FAA and airline users are able to develop and implement effective mitigation plans. As we have seen from the discussion above, this is a very difficult task in congested airspace.

At the last ATM seminar, we emphasized the necessity for integrating weather products such as provided by CIWS with contemporary automation or traffic flow management decision support systems (e.g., URET, CRCT). This was not possible in 2002.

In 2003, we plan to interface the CIWS products to the Route Availability Planning Tool (RAPT) that has been developed by Lincoln Laboratory under the sponsorship of the Port Authority of New York and New Jersey [Delaura and Allan, this workshop]. RAPT identifies times at which a plane may depart from a major airport such that the plane would avoid intersecting convective weather in the terminal airspace and nearby en route airspace by determining whether there are 4D intersections between the expected plane locations and the forecast storm locations. Increased departure rates during severe weather were the most commonly reported CIWS benefit (recall figure 4) in post event interviews in 2002 and hence are an appropriate target for initial weather/ATM integration. Initial testing of RAPT at the end of summer 2002 using 1-hour forecasts from at New York experimental ITWS has shown promising results albeit the initial RAPT operational usage rapidly showed that the RAPT test for plane/storm intersections needs to consider storm echo tops as well as storm reflectivity.

Summary

Significantly improving the ability of the US air system to cope with severe convective weather in congested corridors is a major FAA near term objective. This is a very challenging problem due to:

- the complex dynamical behavior of the en route network flows when there are major unexpected capacity perturbations due to convective weather, and
- the interactions between en route traffic flows and the traffic flows to and from the major terminals within the congested corridors.

In this paper, we have described initial operational results of an effort to reduce delays in the Great Lakes and Northeast corridors through improving the tactical weather detection and forecasting capability. The summer 2002 demonstration system was successful in reducing delays by providing information on storm severity, echo tops and 0-2 hour forecasts to major FAA facilities and airline system operations centers. This initial operational experience and subsequent delay reduction benefits assessment has shown that there are a number of issues that need to be addressed in developing an integrated weather/ATM decision support system for convective weather in these congested corridors:

- the bulk of the convective weather was "unorganized" events, which are particularly difficult to forecast hours in advance; hence multi-hour TFM planning systems need to be able to utilize probabilistic forecasts (as opposed to deterministic forecasts).
- The apparent discrepancies between sector capacity and route capacity as the conceptual

framework for managing traffic flows in rapidly changing conditions need to be better understood and resolved if possible,

- computationally efficient tools need to be developed that can help with the traffic routing/ground-holding optimization when en route and terminal capacities are rapidly changing
- the relationship between convective weather spatial distribution and the effective capacity of en route and terminal sectors is poorly understood at this time, and
- storm vertical structure (e.g., storm echo tops) is a very important factor that needs to be explicitly forecast and considered in assessing the availability of routes and sectors when convective weather is present.

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Biography

Jim Evans is a senior staff member at MIT Lincoln Laboratory and a visiting industrial fellow at the University of California, Berkeley. He has led the Lincoln Laboratory programs to develop the Terminal Doppler Weather Radar (now at 43 major airports), the Integrated Terminal Weather System (ITWS), and the Corridor Integrated Weather System (CIWS). He has authored over 50 publications in refereed journals, conference proceedings and book chapters. He received all (SB, SM and PhD) his degrees from the Massachusetts Institute of Technology (MIT).

Biographies for B. Crowe, M. Robinson and D. Klingle-Wilson will be provided with the paper text provided after the review.